White Paper
**Intel Information Technology**
Computer Manufacturing
Data Storage

# Solid-State Drives in the Enterprise: A Proof of Concept

To determine the potential of solid-state drives (SSDs) to replace hard disk drives (HDDs) in the enterprise, Intel IT conducted a proof of concept (PoC) that included performance tests, measurement of power consumption, and total-cost-of-ownership (TCO) analysis. We found that using SSDs to replace data HDDs in disk arrays could increase I/O performance up to 8x for comparable TCO, and that using them as internal server OS disks reduced the time required for common support tasks such as installs and reboots by up to 73 percent. We plan to perform further testing with selected I/O-intensive enterprise applications to determine benefits and deployment strategies.

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# Executive Summary


To determine the potential of solid-state drives (SSDs) to replace hard disk drives (HDDs) in the enterprise, Intel IT conducted a proof of concept (PoC) that focused on two use cases: replacement of data HDDs in disk arrays to accelerate enterprise applications and replacement of internal server OS HDDs. Our PoC included performance tests, measurement of power consumption, and total-cost-of-ownership (TCO) analysis.

TCO analysis showed that using SSDs to replace high-performance HDDs in arrays could increase I/O performance by up to 8x for comparable TCO.

SSDs, storage devices based on NAND non-volatile memory, are high-performance alternatives to traditional HDDs. Potential benefits include improved TCO for I/O-intensive applications, higher I/O performance in less space, reduced power consumption, and increased reliability.

TCO analysis showed that using SSDs to replace high-performance HDDs in arrays could increase I/O performance by up to 8x for comparable TCO.

We performed tests to measure random I/O performance using Intel® X25-E Extreme SATA Solid-State Drives and HDDs. We also compared SSD and HDD power consumption and operating temperature. Based on our results and other factors, we analyzed the impact of replacing HDDs with SSDs on TCO. We found:

- Tests comparing SSDs with data HDDs in disk arrays showed that SSDs generated significant I/O performance improvements with a broad range of read/write ratios, block sizes, and RAID levels.
- Storage subsystem TCO analysis showed that using SSDs to replace high-performance HDDs in arrays could increase I/O performance by up to 8x for comparable storage TCO.
- Using SSDs as OS disks reduced the time required for common support tasks such as installs and reboots by up to 73 percent.
- SSDs consumed up to 93 percent less power than HDDs.

Following our initial PoC, we plan to perform further testing with selected I/O-intensive enterprise applications to determine benefits and deployment strategies.

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# Business Challenge

Intel IT, like other enterprise IT organizations, continues to explore technologies and solutions to improve the flexibility, agility, reliability, and total cost of ownership (TCO) of our enterprise computing environment.

The performance delivered by server processors has scaled dramatically to help meet these needs: Since 1996, CPU performance has increased 175x, accelerating with the introduction of multi-core processors. However, hard disk drive (HDD) performance lags far behind and has increased only 1.3x in the same period of time..

This imbalance between processor and HDD performance can result in I/O bottlenecks that may limit the ability of IT organizations to take full advantage of processor performance improvements.

HDD performance problems stem from inherent mechanical latency due to moving parts such as disks and disk heads. Mechanical latency can account for more than 95 percent of the total time required to retrieve data from HDDs.

Traditional ways to overcome latency include:

- Adding more spindles, which increases the total number of I/O operations per second (IOPS) that an HDD can achieve.
- Adding more RAM to store working datasets, which reduces the need to access the HDD.

However, these methods both have the disadvantages of increasing server TCO and electrical power consumption.

Solid-state drives (SSDs) have emerged as a high-performance alternative to traditional HDDs, with the potential to influence the economics of the data center.

## SSD Technology Overview

SSDs are data storage devices that use NAND solid-state non-volatile memory to persistently store information. They offer much faster I/O performance than HDDs, with no mechanical latency because there are no moving parts.

SSDs emulate HDDs; they are manufactured in the same form factors as HDDs and use standard HDD interfaces such as Serial Advanced Technology Attachment (SATA). Since SSDs are plug-compatible with HDDs and support standard disk interfaces, they can be installed in most server platforms and disk arrays just like HDDs.

As SSD capacities increase and prices drop, SSDs are becoming an increasingly attractive alternative. Because of their faster performance, SSDs cost much less per IOPS than HDDs. They are also becoming more cost-effective over time in terms of cost per gigabyte (GB). Analysts expect that SSD prices will continue to fall steadily, resulting in increasing enterprise adoption of the technology.

Because of the advantages of SSDs, Intel IT is investigating potential uses of the technology, with the expectation that we will incorporate SSDs into our enterprise IT environment.

## Advantages of SDDs in Data Centers

Replacing HDDs with SSDs can offer several advantages for enterprise data centers.

- **Lower TCO for I/O-intensive applications.** SSDs cost less per IOPS than HDDs, so replacing HDDs with SSDs can reduce storage TCO for I/O-intensive applications. Because fewer SSDs may be needed to deliver the required performance and capacity, IT organizations may not have to spend as much on related infrastructure such as cables, switches, and controllers.
- **More performance in less space.** A single SSD provides much higher IOPS than a single HDD; so for I/O-intensive applications, IT organizations can replace HDDs with fewer SSDs and still obtain higher I/O performance while using less data center space.
- **Greener data centers.** SSDs consume much less power than HDDs, so replacing HDDs with SSDs can reduce overall data center power consumption and cooling requirements.
- **Higher system reliability.** SSDs are inherently more reliable than HDDs due to the absence of moving parts. HDDs experience continual wear and tear due to disk rotation and head movement, which can lead to hard drive failure. In addition, fewer SSDs are required to deliver the same or better I/O performance; fewer drives also leads to greater overall reliability because there is less supporting infrastructure such as switches, controllers, and racks.

## Advantages for Applications

SSDs can potentially offer advantages in a wide range of I/O-intensive applications. These applications fall into two broad categories: high IOPS and high bandwidth.

### High IOPS

High-IOPS applications require high read and write IOPS rates. Typically, they use smaller I/O block sizes of 4 KB to 16 KB. I/O access is predominantly random rather than sequential.

Applications that may have I/O-intensive workloads include:

- **Enterprise applications.** Enterprise resource planning (ERP), enterprise database, and other transaction processing applications.
- **High-performance computing.** Computer-aided design (CAD), computer-aided engineering (CAE), biotechnology simulation, weather forecasting, climate research, seismic analysis in the energy industry, visualization, digital content creation, and nonlinear video editing.
- **Office productivity.** Messaging; database including indexes, logs, and journals; and file system metadata acceleration.

### High Bandwidth

For high-bandwidth applications, the focus is on very high throughput rather than on maximizing the number of IOPS. Typically, they use larger block sizes of 32 KB to 128 KB, with random or sequential I/O access.

Applications that may have bandwidth-intensive workloads include:

- **Enterprise.** Business intelligence, data mining, data warehousing.
- **Internet and multimedia.** Video delivery, video editing, Web serving.

# Proof of Concept

We conducted a proof of concept (PoC) to analyze the potential of SSDs to replace HDDs within Intel's enterprise IT environment.

Our PoC focused on comparing Intel® X25-E Extreme SATA Solid-State Drives with high-performance HDDs. We conducted performance tests and measured temperature and energy consumption. We then performed TCO analysis based on our test results and an assessment of acquisition, support, cooling, and other costs.

We focused on two use cases:

- **Replacement of data HDDs in disk arrays** to accelerate IOPS-intensive and bandwidth-intensive applications. We tested random I/O performance with a range of block sizes, RAID levels, and read/write ratios to represent a broad range of potential applications.
- **Replacement of internal server OS drives** to accelerate everyday support tasks such as software builds, installing patches, and reboots.

## Basic Test Principles

We applied several basic principles throughout our testing:

- Conduct all tests using typical Intel IT server platforms and arrays.
- Use standard platform configurations with default settings, with no enhancements to improve test performance.
- Conduct each test with an equal number of HDDs and SSDs, using equal-sized 100-GB working sets.
- Conduct tests with publicly available tools.
- Perform each test several times to ensure accurate and repeatable results.

## Data HDD Replacement

For these tests, we used a standard Intel IT server with a direct attached storage (DAS) array.

### Test Environment

We used a standard Intel IT two-socket server based on Intel® Xeon® processor X5460 (3.16 GHz, 1333 MHz front-side bus [FSB], 120 watts [W]) with 8 GB of RAM and two internal OS HDDs (73-GB, 10,000 revolutions per minute [RPM]). The server ran a standard Intel IT build with Microsoft Windows Server 2003* using Microsoft Windows NTFS file format.

The server was equipped with a Serial Attached SCSI (SAS) controller with a 512-MB cache. The controller was linked by a four-lane SAS connection

## Solid-State Drive Technologies

While all solid-state drives (SSDs) use non-volatile solid-state NAND memory to persistently store data, two basic technologies differentiate the drives.

In SSDs with single-level cell (SLC) technology, each cell can exist in one of two voltage states and can therefore store a single bit. With multi-level cell (MLC) SSDs, each cell can exist in one of four voltage states and can thus store two bits.

The advantages of each technology are summarized in Table 1. SLC SSDs offer faster performance for write operations and greater reliability. MLC SSDs can store information at a greater density and cost less per gigabyte. Additionally, SSDs with SLC technology have greater endurance: They are typically developed to withstand 100,000 write cycles compared with 10,000 cycles for SSDs with MLC technology.

As a result of these differences, the two types of drives tend to be targeted at different applications. SLC SSDs are ideal for enterprise applications requiring the highest read and write performance and reliability, such as online transaction processing (OLTP), databases, data warehousing, enterprise resource planning (ERP), and business intelligence. MLC SSDs are well suited for read-intensive enterprise applications and others such as Web or video serving. They also offer a lower price point and higher capacity.

In our PoC, we used Intel® X25-E Extreme SATA Solid-State Drives due to their industry-leading performance and endurance. These characteristics meet our requirements for enterprise applications.

**Table 1. Comparison of Solid-State Drive Technologies**

| | Single-level Cell Technology | Multi-level Cell Technology |
|---|---|---|
| Higher performance—read and write | X | |
| Greater reliability—cycling and bit error | X | |
| Lower cost per gigabyte | | X |
| Greater density reach | | X |
| Endurance | X | |

to a DAS array that accommodated up to 25 drives and supported both the SAS and SATA drive interfaces. The interfaces effectively limited the throughput of drives in the array to about 1.5 GB.

For each test, we installed the appropriate type and number of drives into the array. Configurations included:

- 5 or 10 HDDs (15,000 RPM, 73 GB)
- 5 or 10 Intel X25-E Extreme SATA Solid-State Drives (32 GB)

The test environment is shown in Figure 1.

## Test Tools

We generated and measured I/O operations using Iometer 2008.06.18, an open-source tool originally developed by Intel. Iometer is both a workload generator that performs I/O operations in order to stress the system and a measurement tool that examines and records the performance of its I/O operations and their impact on the system. We used Iometer to generate a wide range of different workloads with different read/write ratios and block sizes.

We monitored SSD and HDD power consumption using Intel Power Acquisition Recording Kit (iPARK).

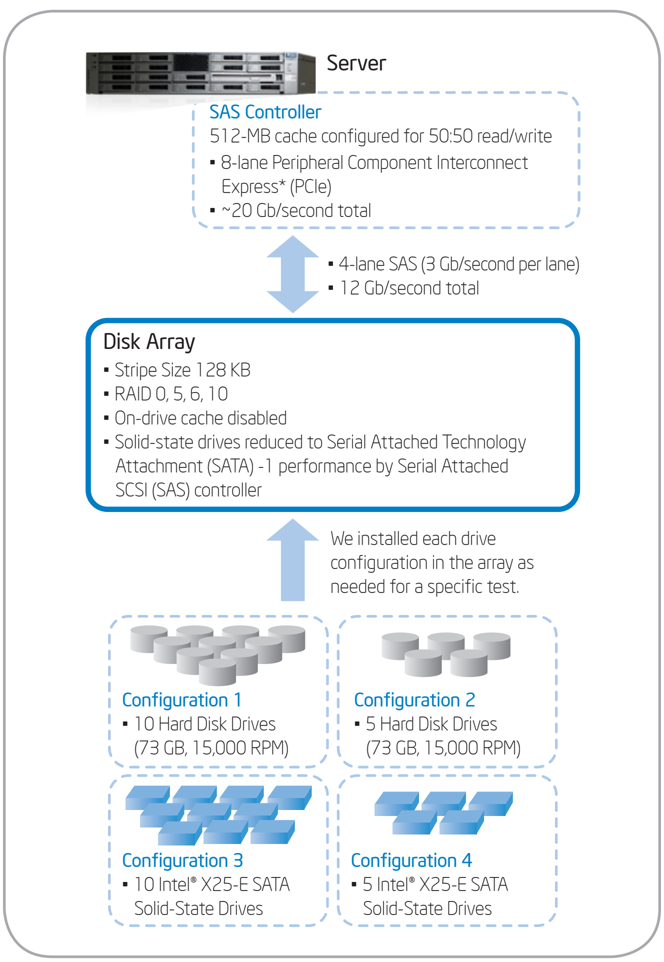



**Figure 1. Data HDD replacement test environment.**

## Test Method

We generated a range of random workloads and ran them in our test environment, comparing SSD and HDD performance in each case.

Variables included:

- **Read/write ratios.** We used ratios ranging from 100 percent read to 100 percent write.
- **Block sizes.** We used block sizes ranging from 4 KB to 128 KB.
- **RAID levels.** We configured the HDD and SSD with a range of RAID levels: 0, 5, 6, and 10.

For each test, we used Iometer to generate one-minute test runs with a 10-second ramp. We performed each test at least three times to verify accuracy and repeatability.

We configured Iometer with the following workload parameters:

- 1 worker—a single-threaded load
- Queue depth of 32
- Working set size of 100 GB

We configured the SAS controller cache as follows:

- Read/write ratio of 50:50
- RAID stripe size of 128 KB
- On-drive cache disabled

We used iPARK to monitor array power consumption when idle and under load.

### RAID rebuild

We also compared the time needed to complete a RAID 5 rebuild using SSD and HDD configurations. This is a typical support operation that might be required in the event of a disk failure.

## Data Analysis Method

To make it easier to compare SSD performance with HDD performance, we normalized our test results for analysis. We calculated SSD performance relative to the performance observed with HDDs in the same test.

## Performance Test Results

SSDs delivered substantial I/O performance improvements over HDDs at all read/write ratios, block sizes, and RAID levels. We performed detailed analysis that focused on two areas, selected because they are extensively used for enterprise IT workloads:

- RAID 5 configurations with different block sizes
- Block size of 4 KB with different RAID levels

### RAID 5 configuration with different block sizes

We performed a detailed comparison of SSD and HDD performance in a RAID 5 configuration, which is commonly used for enterprise applications.

We compared performance with different block sizes and read/write ratios, representing a range of different applications and situations. Results are shown in Figure 2.

Absolute performance with SSDs was as high as 22,000 IOPS for a random I/O read-only workload using 4-KB block sizes in the RAID 5 configuration. This was about 13x the 1,715 IOPS achieved in the equivalent HDD test.

We also observed significantly higher performance with all read/write workloads. This was the case for all block sizes and all read/write ratios, from 80:20 read/write to 100 percent write. With the smaller block sizes (4 KB to 16 KB) typically used by high-IOPS applications such as ERP, SSDs delivered 4x to 7x the performance of HDDs. With the larger block sizes (32 KB to 128 KB) commonly used for high-bandwidth applications such as Web and video serving, SSDs delivered 2x to 5x the performance of HDDs.

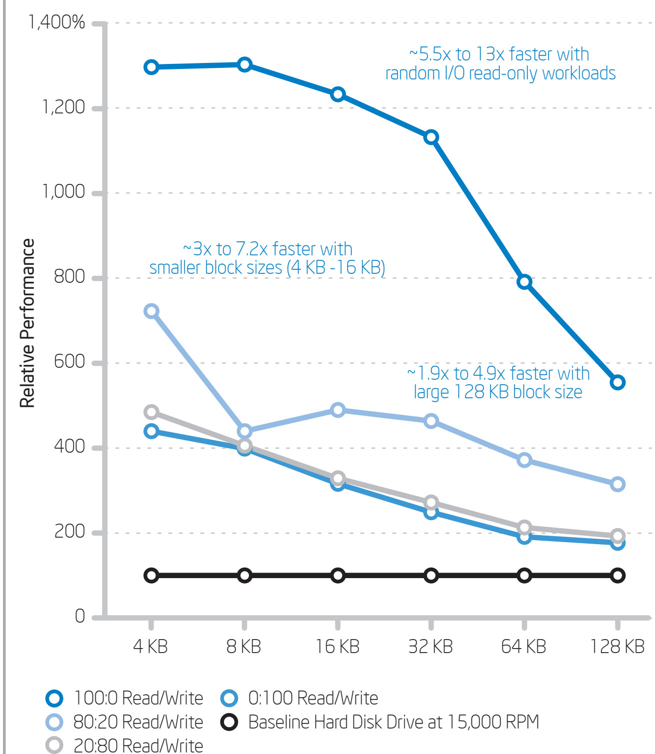
### 4-KB block size with different RAID levels

We also analyzed performance with a 4-KB block size at different RAID levels: RAID 0, 5, 6, and 10. The standard Microsoft Window NTFS block size is 4 KB, and this is widely used for transaction-oriented applications.

For each RAID level, we compared SSD performance relative to HDDs configured at the same RAID level. Results are summarized in Figure 3.

With SSDs, random I/O read-only performance was 10x to 15x that of HDD performance at all RAID levels. Performance with read/write workloads was up to 7.2x higher with SSDs compared to HDDs.

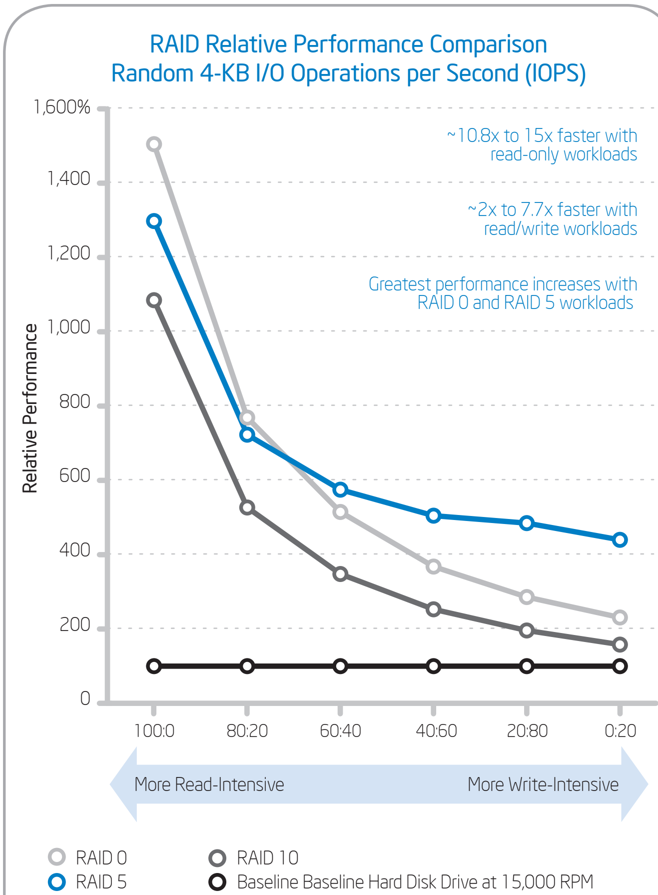
RAID 5 Random I/O Relative Performance Results




RAID 5 Performance Examples from Absolute I/O Operations per Second (IOPS) Test Results

| | Absolute IOPS | | |
|---|---|---|---|
| | Hard Disk Drive (73 GB, 15,000 RPM) | Intel® X25-E SATA Solid-State Drive | Percent Difference |
| **Read-only** | | | |
| 4 KB | 1,715 | 22,265 | 1,298% |
| 16 KB | 1,339 | 16,517 | 1,234% |
| 128 KB | 711 | 3,946 | 555% |
| **80:20 Read/Write** | | | |
| 4 KB | 1,314 | 9,505 | 723% |
| 16 KB | 1,091 | 5,346 | 490% |
| 128 KB | 541 | 1,703 | 315% |
| **20:80 Read/Write** | | | |
| 4 KB | 791 | 3,835 | 485% |
| 16 KB | 668 | 2,198 | 329% |
| 128 KB | 326 | 630 | 193% |

**Figure 2. Results of data HDD replacement tests.** Relative performance of SSDs compared with HDDs in RAID 5 configuration. Random I/O workloads with different block sizes and read/write ratios. Intel internal measurements 2009.




4-KB Blocks, Different RAID Levels
Examples from Absolute IOPS Test Results

| | Absolute IOPS Hard Disk Drive (73 GB, 15,000 RPM) | Intel® X25-E SATA Solid-State Drive | Percent Difference |
|---|---|---|---|
| Read-only | | | |
| RAID 0 | 1,492 | 22,454 | 1,505% |
| RAID 5 | 1,715 | 22,265 | 1,298% |
| RAID 10 | 1,978 | 21,470 | 1,085% |
| 80:20 Read/Write | | | |
| RAID 0 | 1,602 | 12,310 | 768% |
| RAID 5 | 1,314 | 9,505 | 723% |
| RAID 10 | 2,086 | 10,992 | 527% |
| 20:80 Read/Write | | | |
| RAID 0 | 2,083 | 5,949 | 286% |
| RAID 5 | 791 | 3,835 | 485% |
| RAID 10 | 2,410 | 4,731 | 196% |

**Figure 3. Data hard disk drive (HDD) replacement tests.** Relative performance of solid-state drives compared with HDDs at different RAID levels. Random I/O workloads with 4 KB block sizes and different read/write ratios.

Across the range of read/write ratios tested, SSDs provided the greatest overall performance gains over HDDs in RAID 0 and RAID 5 configurations. At these RAID levels, I/O performance with SSDs averaged 3.3x to 4.4x the performance with HDDs.

### RAID 5 Rebuild Test Results

The RAID 5 rebuild completed 35 percent faster with SSDs compared to HDDs. The time required was 9 minutes 24 seconds with SSDs and 14 minutes 25 seconds with HDDs.

## OS Drive Replacement

We assessed the potential of SSDs to accelerate common support and maintenance tasks when used as replacements for internal server OS hard drives.

### Test Method

We performed common support tasks—building the OS, booting the server, installing an OS update, and defragmenting disks—on a typical Intel IT server with three internal HDDs. We performed each task at least three times and calculated the average time.

Then we replaced the HDDs with SSDs and repeated the tests, omitting the disk defragmentation test. Disk fragmentation is an issue with HDDs because it increases mechanical latency due to the need for more disk head movement. With SSDs, fragmentation does not affect the time required for read or write operations, so there is no need for defragmentation.

### Test Results

All the support tasks completed more quickly with SSDs. For the most common tasks, booting and installing a software update, completion times were 73 percent and 31 percent faster, respectively. Results are shown in Figure 4.

## Power Consumption and Temperature

We measured power consumption and temperature of a single SSD and a single HDD when operating under load during our tests and when idle.

Under load, the SSD consumed 0.9 W, 91 percent less than the 10.1 W consumed by the HDD. It also operated at a much lower temperature of 94 degrees Fahrenheit (° F) compared with 154° F for the HDD.

At idle, the SSD consumed 0.5 W, 93 percent less than the 6.88 W consumed by the HDD.

## TCO Analysis

We analyzed the TCO impact of using SSDs to replace HDDs in arrays and internal server OS drives.

To do this, we created a TCO calculator that takes into account a range of factors, including the results of our tests. We used the calculator to project the impact on storage subsystem TCO of replacing typical array and OS HDD configurations with SSDs.

Our analysis focused purely on capital and operational costs and did not take into account the potential value of productivity benefits due to performance improvements delivered by SSDs. We included data center power and cooling costs. Inputs to our TCO calculator included:

- Results of performance tests
- Measurements of power consumption
- Typical Intel IT hardware costs
- Maintenance and warranty costs
- Replacement and repair costs derived from industry averages and an analysis of historical Intel IT HDD repair costs; we assumed an annual failure rate of 4 percent for HDDs and 0.5 percent for SSDs.
- Published specifications for HDDs and SSDs

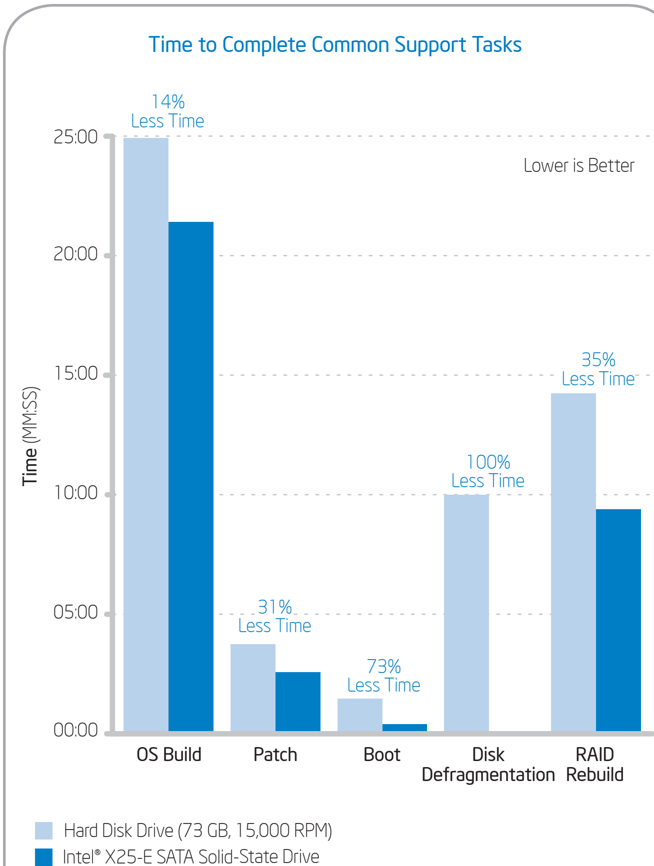
Our TCO analysis results are estimates based on our measurements and assumptions. Results may vary depending on the situation and specific products used.

### Usage Model: High-Performance Application Data Array

In this analysis, we compared high-performance HDD and SSD configurations designed to deliver a minimum of 400 GB of capacity and 2,000+ random IOPS for a workload with a read/write ratio of 80:20 and 4-KB block size.

Our high-performance HDD array design was comprised of eight Fibre Channel (FC) HDDs (15,000 RPM, 146 GB) in an FC-connected array. We assumed these were configured as RAID 10 to maximize performance, with 70 percent of capacity used. This design met both capacity and I/O requirements.

Our candidate SSD-based replacement consisted of eight Intel X25-E Extreme SATA Solid-State Drives (64 GB). We based our assessment on a RAID 5 SSD configuration because of the significantly greater reliability and I/O performance of SSDs relative to HDDs. This design met the capacity requirement and greatly exceeded the minimum IOPS requirement.




| | Hard Disk Drive (73 GB, 15,000 RPM) | Intel® X25-E SATA Solid-State Drive | Percent Difference |
|---|---|---|---|
| **OS Build** (Microsoft Windows 2003 Server*) | 24:55 | 21:25 | 14% |
| **Patch** (Service Pack 2) | 03:45 | 02:35 | 31% |
| **Boot** | 01:28 | 00:24 | 73% |
| **Disk Defragmentation** | 10:00 | 00:00 | 100% |
| **RAID Rebuild** (5x RAID 5) | 14:24 | 09:24 | 35% |

**Figure 4. Time to complete common support tasks.**

### Results

Based on our analysis, the SSD configuration would deliver 8x the I/O performance, a 35 percent faster array rebuild time, and 97 percent lower power consumption—all for roughly comparable TCO. TCO is shown in Figure 5. Although SSDs have a much higher cost per GB, this is partially offset by the ability to use a more space-efficient RAID algorithm with SSDs due to their greater reliability and to optimize space utilization (100 percent versus 70 percent) due to their better I/O density.

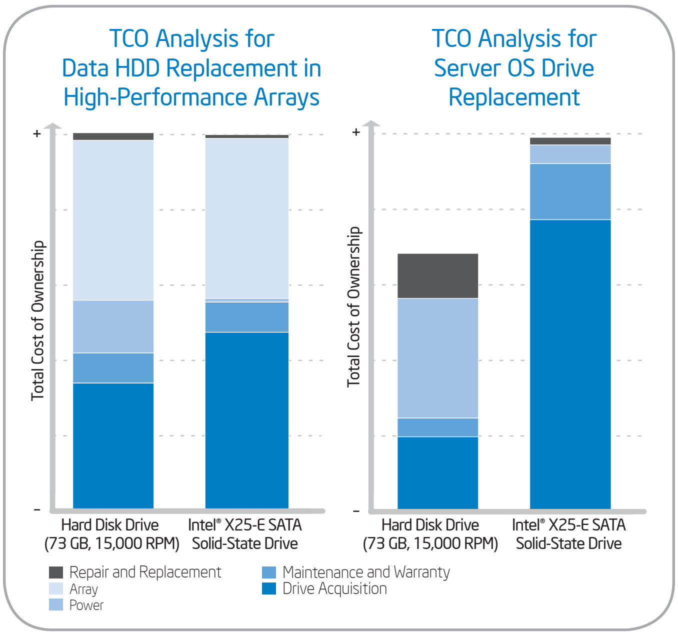



**Figure 5. Total cost of ownership (TCO) analysis for data HDD replacement in high-performance arrays and for server OS drive replacement.**

## Usage Model: OS Drive Replacement

We assumed a current HDD configuration consisting of two SAS HDDs (10,000 RPM, 73 GB). These were configured as RAID 1, with 70 percent used capacity, providing about 50 GB of available capacity.

Our potential SSD configuration consisted of three Intel X25-E Extreme SATA Solid-State Drives (32 GB) configured as RAID 5, for a total available capacity of 96 GB.

We based our analysis on a random I/O workload with a read/write ratio of 80:20 and a 4-KB block size.

### Results

With SSDs, storage subsystem estimated TCO increases by 46 percent, also shown in Figure 5. Boot times decrease by 73 percent, and server build and patch times decrease by an average 40 percent. Total power consumption is 85 percent lower.

Although TCO is higher with SSDs in this analysis of OS drive replacement, the faster performance could result in substantial productivity improvements. These improvements could deliver significant value to IT organizations. Depending on the situation, this could outweigh the increase in TCO.

# Key Learnings

The experience we gained during the PoC provided several insights that we anticipate will be useful as we continue to investigate enterprise use of SSDs.

## Performance and Ecosystem Readiness

Our tests confirmed that using SSDs in typical Intel IT array and server configurations substantially accelerates I/O performance. For random I/O-intensive workloads, our analysis indicated 8x the performance for comparable TCO.

However, the performance that SSDs can deliver is currently limited by the storage ecosystem.

Current RAID methods do not appear to take full advantage of low-latency SSDs. The algorithms in RAID controllers attempt to optimize the performance of an array of HDDs with their rotating media and associated latencies. Algorithms that are optimized for SSDs could deliver further significant performance improvements. In addition, the SAS and SATA interfaces can limit array throughput, and not all DAS or storage area network (SAN) arrays support SSDs.

In the future, greater I/O performance improvements should be possible with interfaces optimized for solid-state storage.

## Endurance and Reliability

We expect SSDs to be more reliable than HDDs in enterprise use, but there is limited enterprise reliability data because enterprises have only recently begun to deploy SSDs. Within Intel IT, our experience to date has been favorable. For example, we have written about 130 TB of data to a single Intel X-25E SATA Solid-State Drive (32 GB) over approximately 4 months.

## Costs

SSD prices are falling rapidly, but HDD prices also continue to decrease. SSDs cost less per IOPS but are not expected to achieve price parity per GB. The benefits of SSDs lie in the greater performance they deliver, lower power consumption, and potentially reduced support costs due to higher reliability.

## Capacity

The capacity of SSDs is rapidly increasing, and this will significantly improve TCO. For example, compared with five 64-GB SSDs, a single 320-GB SSD occupies only one fifth of the space in an array. As SSD capacity increases, enterprises will need less storage infrastructure to deliver a given level of IOPS performance, resulting in improved TCO.

# Areas for Future Investigation

Developments based on SSD technology could deliver many enterprise benefits. Potential or planned areas for future investigation include:

**Enterprise applications.** We are planning to perform further testing with selected I/O-intensive enterprise applications to determine benefits and deployment strategies.

**Secure erase.** Secure erase –physically overwriting every block on the disk so all data is erased—may be required by some organizations and can help all businesses ensure that they comply with federal data-protection regulations. However, with HDDs this process is time-consuming and therefore expensive. Potentially, data on SSDs could be surely erased much more quickly at lower cost.

**Transparent compression.** SSDs are becoming less expensive, but still cost more per GB than HDDs. Using compression to store more data on each SSD could result in sizable savings.

**Hybrid SLC and MLC devices.** Hybrid devices could reduce overall price per GB by combining the performance of SLC SSDs with the lower cost per GB of MLC SSDs.

**Encryption.** Onboard encryption could reduce cost by eliminating the need to buy separate encryption software.

# Conclusion

Intel IT tests confirmed that SSDs provide substantial performance improvements over HDDs and much lower cost per IOPS, as shown in Figure 6.

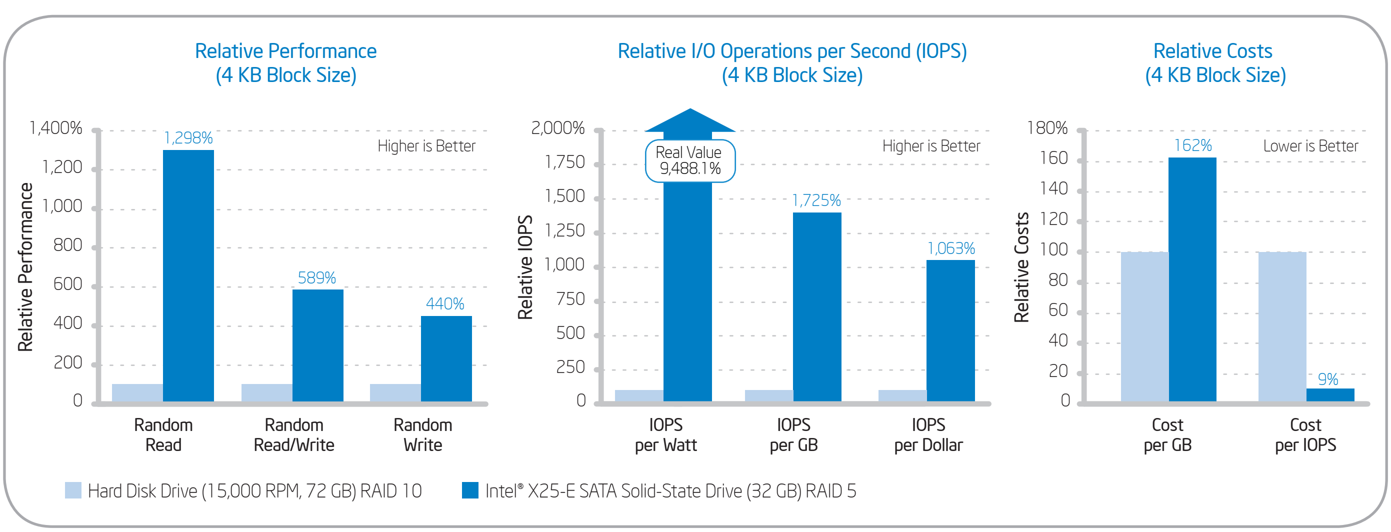



**Figure 6. Summary of results comparing solid-state drives to hard disk drives.**

Our test results and analysis indicate that when used to replace data HDDs in arrays, SSDs could deliver improved TCO as well as much higher performance for a broad range of I/O-intensive applications. When used to replace OS drives in servers, SSDs significantly accelerated everyday support tasks such as builds and patches. We also observed much lower power consumption.

We expect further benefits as the storage ecosystem evolves to better take advantage of SSDs.

Obtaining the maximum benefit from SSDs requires a shift in how we think about disk performance. Current write caching assumptions may not apply, disk fragmentation is no longer an issue, and current RAID approaches—designed to improve performance with high-latency HDDs—may be less effective with SSDs.

Following this initial PoC, we plan to perform further testing with selected I/O-intensive enterprise applications to determine benefits and deployment strategies.

## Authors

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## Acronyms

| | |
|---|---|
| DAS | direct attached storage |
| FC | Fibre Channel |
| GB | gigabyte |
| HDD | hard disk drive |
| IOPS | I/O operations per second |
| MLC | multi-level cell |
| OLTP | online transaction processing |
| PoC | proof of concept |
| RPM | revolutions per minute |
| SAS | Serial Attached SCSI |
| SATA | Serial Advanced Technology Attachment |
| SLC | single-level cell |
| SSD | solid-state drive |
| TCO | total cost of ownership |
| W | watt |



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